ARPA-E CHANGING WHAT'S POSSIBLE

The Energy-Smart Farm

Distributed Intelligence Networks for Highly Variable Resource Constrained Crop Production Environments

February 13, 2018

Energy-Smart … Smart-Farm

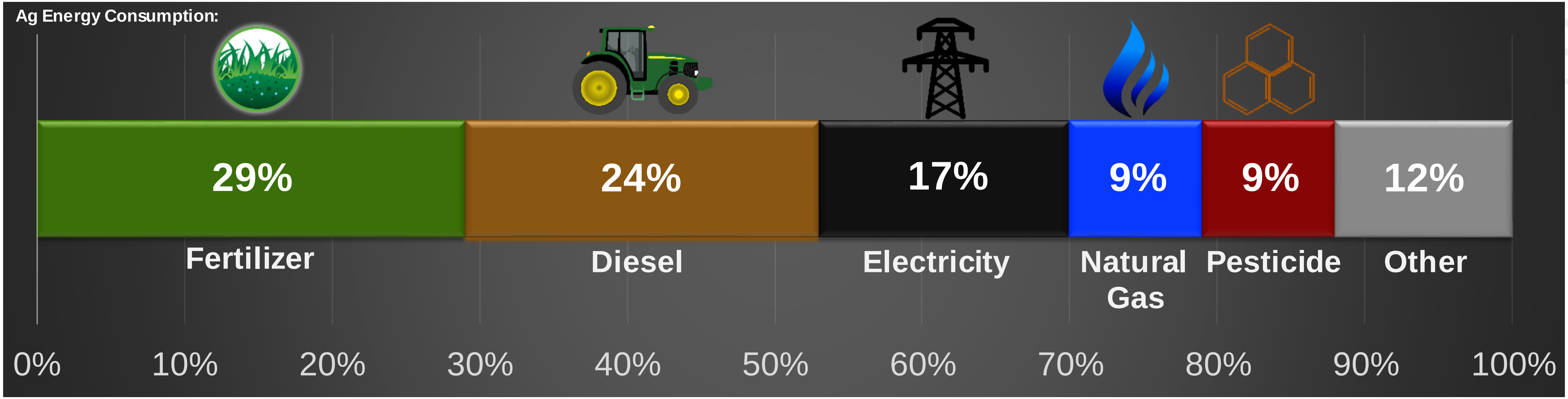
Imagine… an Ag Sector

That in the next thirty years:

✓ Doubles Productivity	(2x Yield)
✓ Cuts Emissions in Half	(5% GHG)
✓ Conserves Resources	(30% Water)
✓ Triple Renewables	(1B Tons Biomass)

Agricultural is BOTH a Consumer and Producer of U.S. Energy

In 2014 the Agricultural Sector Consumed 1.7 Quadrillion BTU of Energy…



… and Generated 4.9 Quadrillion BTU of Primary Energy from Biomass

With Unintended Consequences: 9% U.S. GHG Emissions and 80% U.S. Fresh Water Use

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- USDA. Trends in US Agriculture's Consumption and Production of Energy: Renewable Power, Shale Energy, and Cellulosic Biomass. United States Department of Agriculture, Economic Research Service, 2016.
- NREL. 2014 Data Book.
- EPA. Sources of Greenhouse Gas Emissions. 2014.
- Schaible, G. Aillery, M. Water Conservation in Irrigated Agriculture: Trends and Challenges in the Face of Emerging Demands. (2012)

U.S. has Capacity to Produce >1.4 Billion dry tons of Biomass

Without Impacting Food or Export

Potential Bioenergy Feedstocks: High-yield scenario

New Forestry
142
million dry tons

New Ag Residue
200
million dry tons

New Energy Crops
736
million dry tons

Current Agriculture + Forestry Bioenergy Feedstocks
365 million dry tons

U.S. Department of Energy 2016 BILLION-TON REPORT

Advancing Domestic Resources for a Thriving Bio-economy

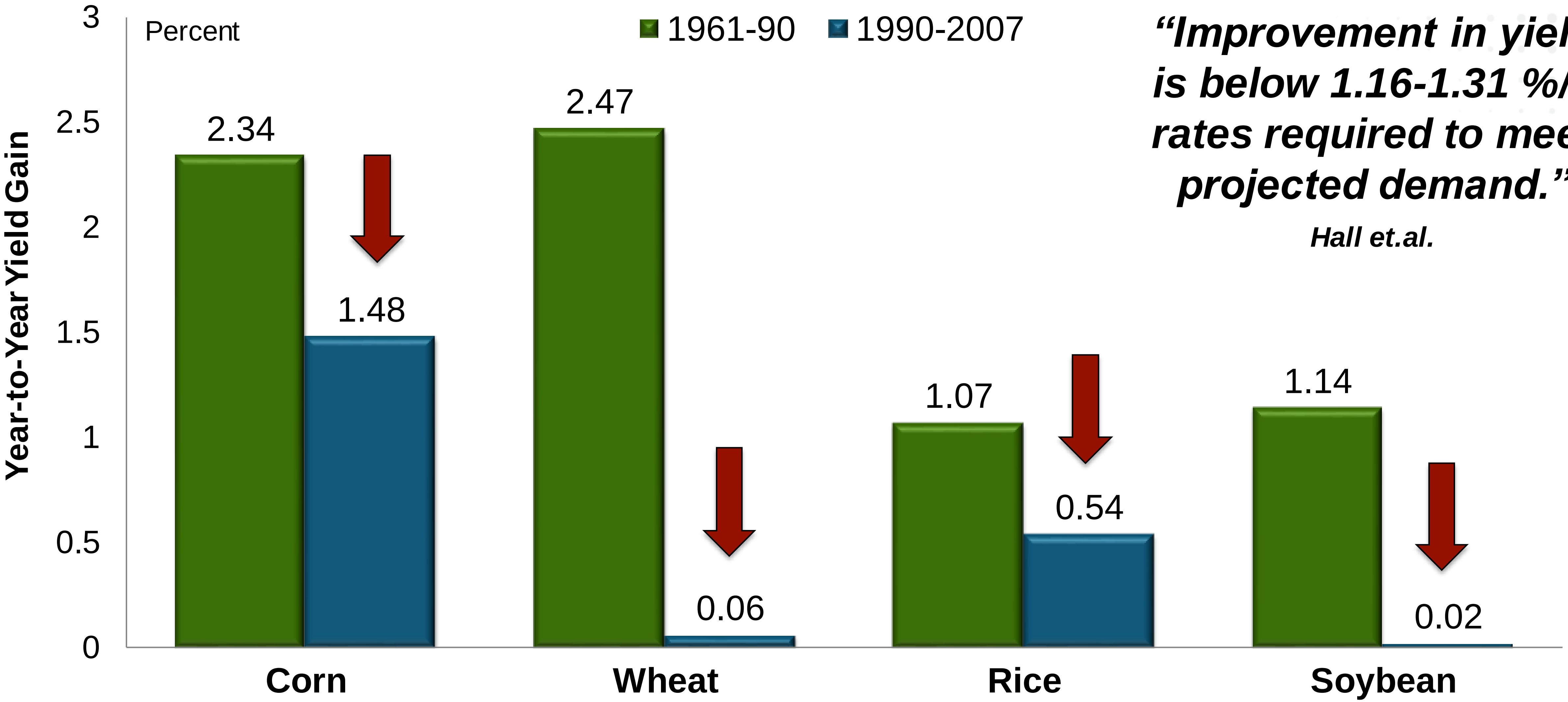
Domestically, 1.4 Billion dry tons biomass could be available by 2040:

- At a roadside price of $60/DT
- From a diversity of biomass resources (annual & perennial)
- **2-4% annual crop genetic gain**

With the Potential to Supply 20% of U.S. Energy Demand

We Are Off the Pace to Feed and Fuel the World

Evidenced by Declining Rate of Genetic Gain in Core Crops



"Improvement in yield is below 1.16-1.31 %/y rates required to meet projected demand."

Hall et.al.

- FAOSTAT 2009
- *Prognosis for genetic improvement of yield potential of major grain crops*. A. J. Hall, R. A. Richards, Field Crops Research, 143 (2013) 18-33.

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Fossil Fuels Enabled the First Green Revolution…

…but Future Productivity Relies on Data!

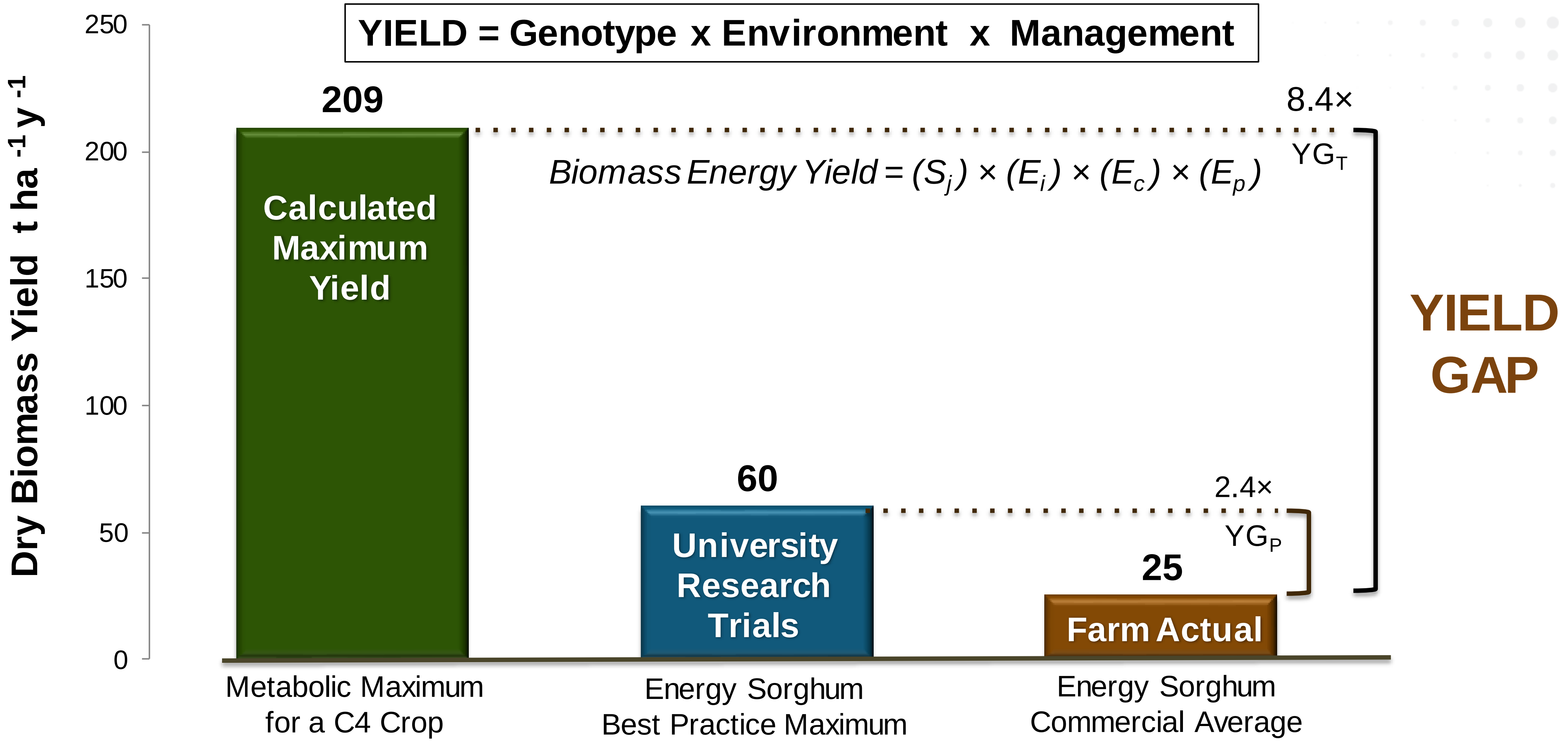
Productivity gains during the 20th century were achieved by leveraging existing technologies:

- Irrigation infrastructure
- Synthetic fertilizers
- Chemical pesticides
- Crop varieties

The 21st century requires a new revolution that will sustainably double crop productivity in the face of competition for arable land and increasing exposure to climatic shocks

Crop Feedstocks Have Significant Upside Genetic Potential

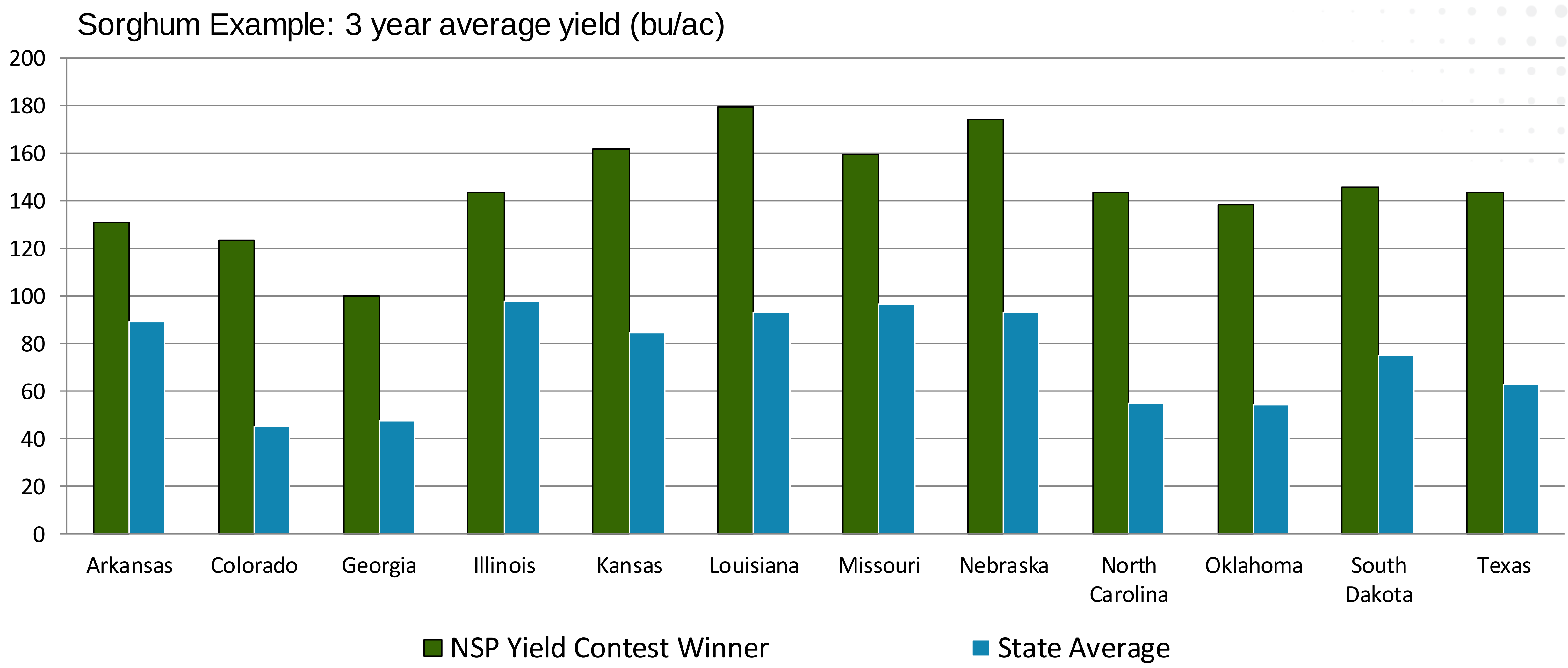
Energy Sorghum Example



Energy content of dry biomass ~17 MJ/kg

Yield Contest Winners Reveal a 60-100% Yield Gap

Best Management Practice vs State Average



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NASS and complements of John Duff at the United Sorghum Checkoff Program

Famers Make Over 40 Yield-Impacting Decisions Each Season

YIELD = Genotype x Environment x Management

Planning
- Rotation
- Genetics
- Inputs

Pre-Plant
- Field Selection
- Field Tillage
- Fertilizer App

Planting
- Planting Date
- Seeding Rate
- Pest Control

In-Season
- Irrigation
- Nutrients
- Pest Control

Harvest
- Harvest Date
- Storage
- Marketing

- Planting Date and Harvest Timing can result in a 10% swing in yield
- No silver bullet … impacts fall ~1-3% but add up quickly

Due Diligence: Opportunity for Distributed Intelligence

Problem: In-Field Variability Complicates Management and Increases RISK

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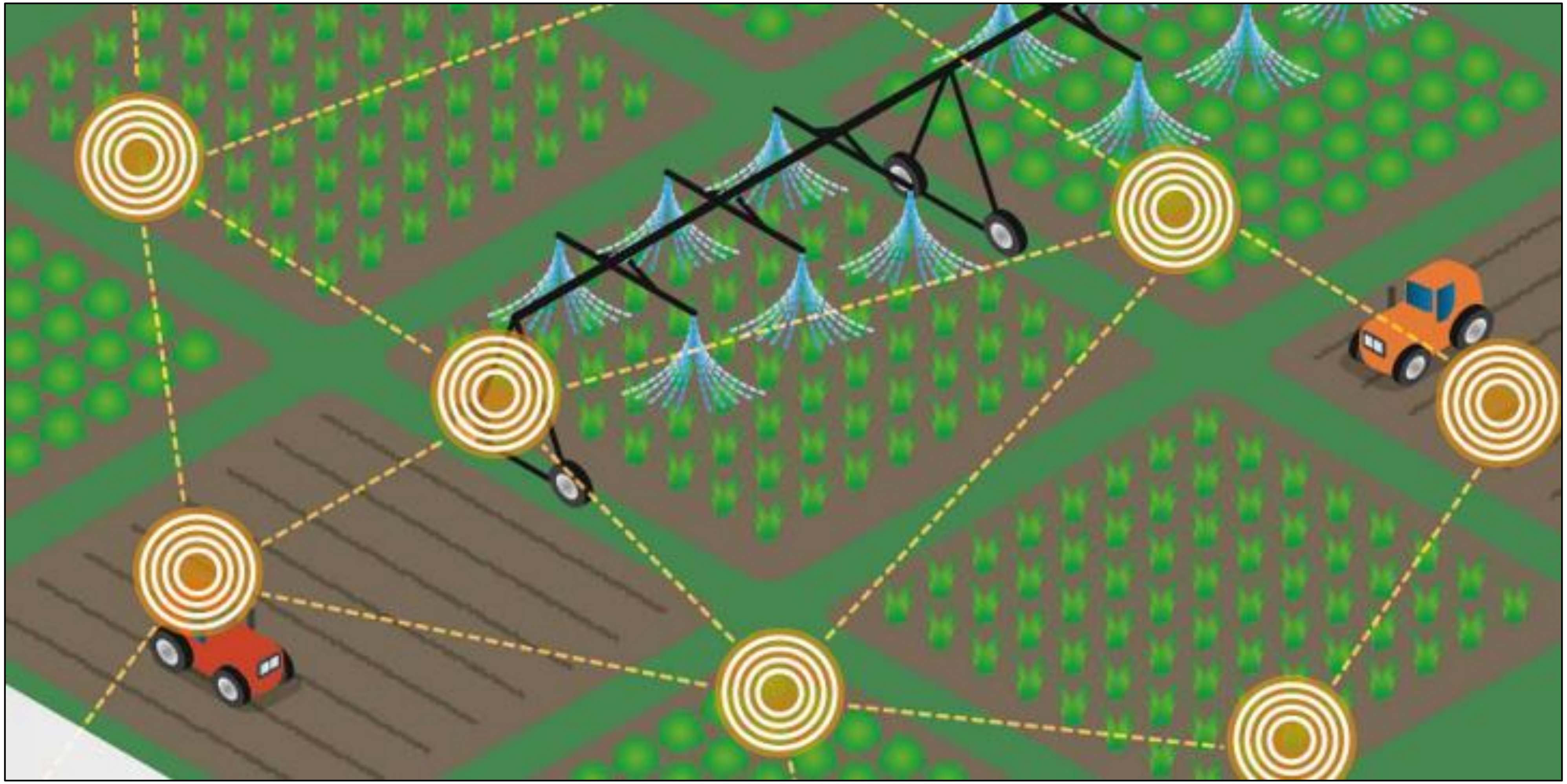
Due Diligence: Opportunity for Distributed Intelligence

Solution: In-Field Spatiotemporal Monitoring



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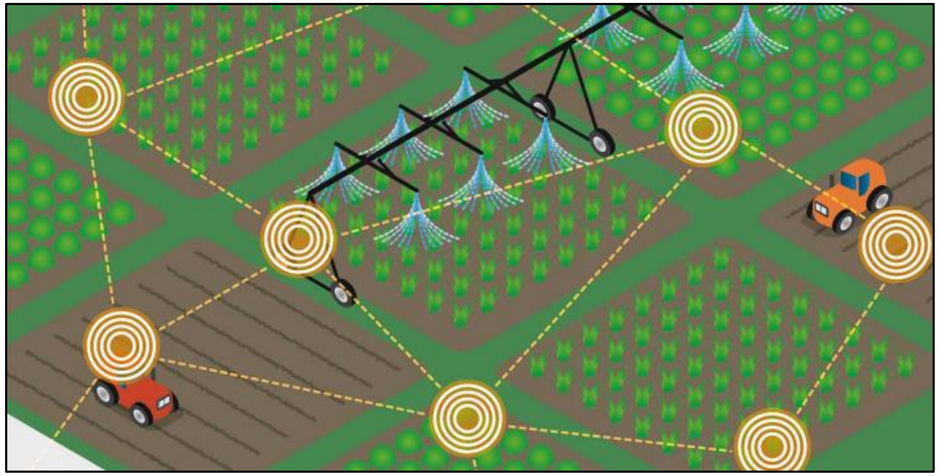
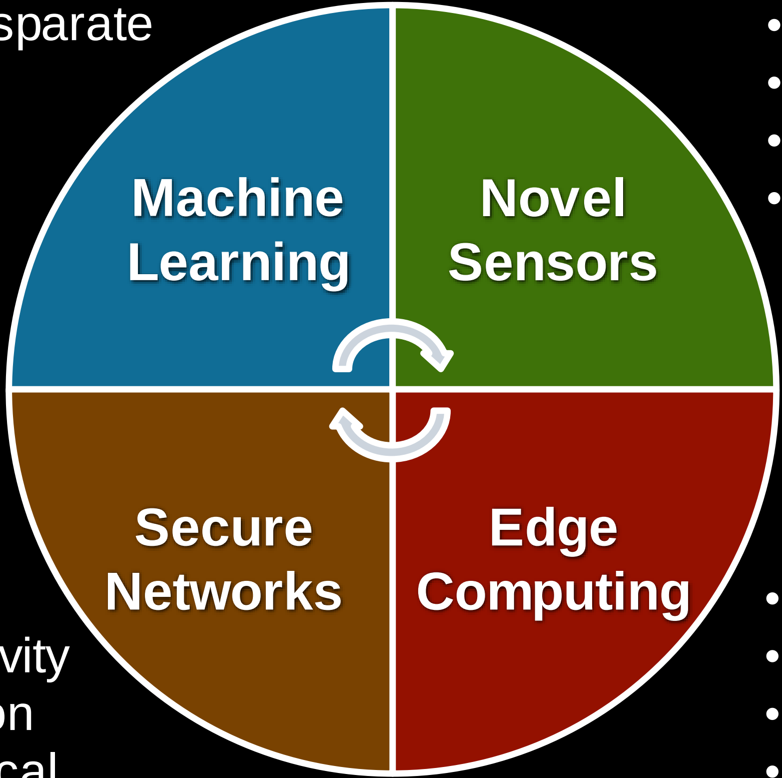


Distributed Intelligence Networks for Highly Variable Resource Constrained Crop Production Environments

- Large Disparate Datasets
- Relevant
- Secure

- Accurate
- Reliable
- Compact
- Economical



- Scalable
- Connectivity
- Encryption
- Economical

- Power
- Speed
- Size
- Storage

Due Diligence: Emerging Breakthrough Technologies

Capturing, Storing, Communicating, Processing, and Predicting

Innovation Frontiers:

Sensing: microclimate, metabolic, chemical, nutrient, biologic, acoustic

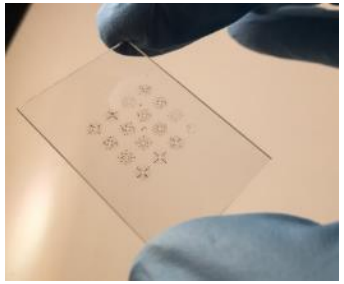
Power: zero power, energy harvesting, non-toxic, bio-electrons

Analytics: no central hub, ML without full datasets, multiscale crop models

Communications: no line of site, swarm coordination, just in time

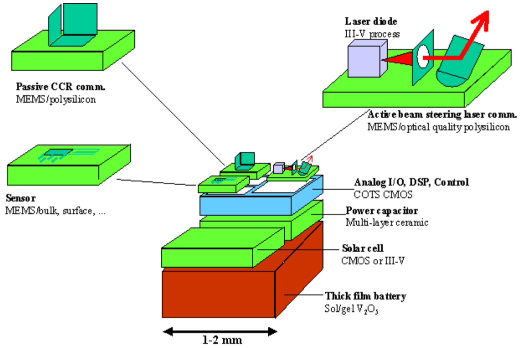
Examples:

Printed Circuits



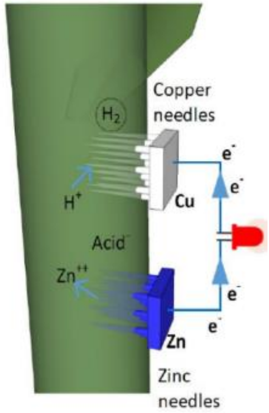
MIT Technology Review. Printed Electronics. 2017.

Lab on a Chip



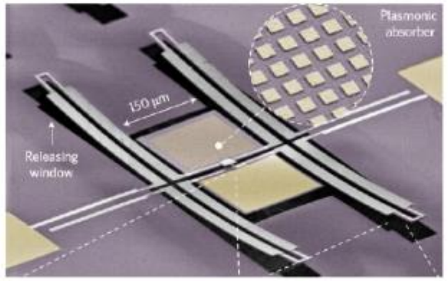
Harbin, J. R. Security Strategies In Wireless Sensor Networks. 2011.

In Planta Batteries



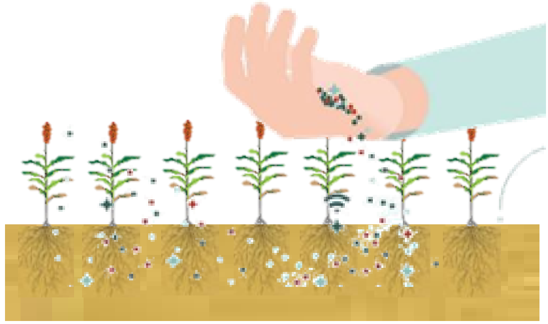
Schnable, P. et al. Iowa State. 2017

Ultra-Low Power Platforms



Z. Qian et al. Zero-power infrared digitizers based on plasmonically enhanced micromechanical Photoswitches. 2017

Ultra-Compact Computers



Program Hypothesis: The Data-Driven Energy-Smart Farm

Rooted in Biology, Powered by Engineering, Enabled by Analytics

Develop new innovative technologies and decision support tools that maximize sustainable economic returns by increasing yields, conserving resources, and creating new market opportunities.

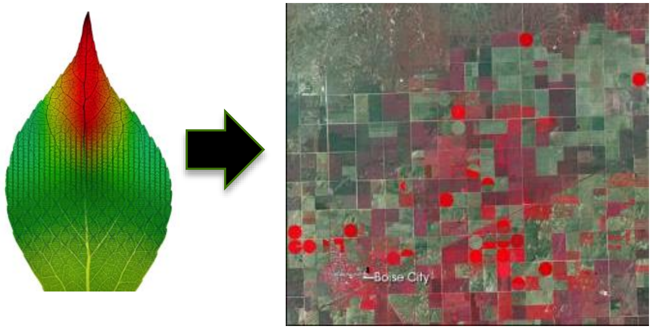
Deploy high-resolution wireless sensing systems

+

Monitor biotic and abiotic conditions that limit growth

+

Integrate multiscale, multimodal datasets



Program Challenge: Design, Build and Test

- **Create a fully integrated, low-cost, scalable sensor network with:**
  - Communication connectivity standards
  - State of the art computational capabilities
  - System-wide data security protocols

  …in a highly variable resource constrained environment.

- **Implement a prototype broad-acre decision support ecosystem:**
  - Monitor real time abiotic stress (water, temperature, nutrients, etc.)
  - Monitor real time biotic stress (pathogens, insects, weeds, etc.)
  - Monitor real time environmental conditions (light, moisture, soil, etc.)
  - Make prescriptive management decisions with a yield and economic prediction.
  - Integrate data pipelines and system components into a user-friendly interface.

Moving Past the Hype:

Distributed Intelligence is ARPA-E-hard!

- Technical challenges are application agnostic:
  - Available tools and technologies often ***do not follow the same standards/platforms.***
  - In many remote locations, ***strong, reliable internet connectivity and power are not available.***
  - It is next to ***impossible to monitor and manage every single data point*** - technology is only useful when users can make sense of the data.
  - Operating parameters and performance targets are not uniform (large differences between crops); ***systems need to be flexible in deployment and operation.***
  - ***Automation advances – and the operational efficiencies expected from them - are limited to available data.***
  - ***Failure/breakdown is unacceptable.***
  - ***Security is essential.***

WORKSHOP: What Does a Transformational System Look Like?

System Metrics

- Availability… cost and size
- Performance... power, speed, storage and computation
- Connectivity... range and bandwidth
- Reliability... mean down time
- Relevance... simplicity and utility

Sample Metrics

- Establish low-power/high-bandwidth connectivity within the farm
- Dense deployment of sensor network across the farm (1 to $10m^2$)
- Scalable to 200 hectares by year 4 (average U.S. Farm size 2016)
- One complete crop cycle (12 Months) pre plant to post harvest
- Less than 10% system failure down time
- System cost 2 orders of magnitude cheaper/faster than SOA

Workshop Agenda:

Rooted in Biology, Powered by Engineering, Enabled by Analytics

Day 1: Platform Priorities

Table by Table	Attendee Introductions
Dr. Cristine Morgan	Sensing for Yield and Energy-Smart Farming - Soil
Dr. Cara Gibson	Sensing for Yield and Energy-Smart Farming - Pests
Dr. John Antle	Agricultural Systems Science
Dr. Brian Anthony	SENSE.nano: Lessons from Medicine & Industrial IoT
Dr. Troy Olsson	N-ZERO: Low-Power Sensing
Dr. Frank Libsch Dr. Robin Lougee	Micro-Sensor Platforms and Machine Learning at IBM
Parker Liautaud	Breakout Overview, Move to Breakout Rooms
Breakout Session 1	
Group 1	Bioenergy Crop Production Priorities
Group 2	Abiotic Sensors & Platforms
Group 3	Biotic Sensors & Platforms
Group 4	Decision Support Analytics

Day 2: System Design

Dr. Michael Wang	Bio-Product Life Cycle Analysis
Dr. Kevin Dooley	Supply Chain Alignment of Farm-Level Metrics
Raja Ramachandran	Transforming Agricultural Supply Chains
Break	
Dr. Ranveer Chandra	FarmBeats: End-to-End Design of IoT for Agriculture
Parker Liautaud	Breakout 2 Introduction, Move to Rooms
Breakout Session 2	
Group 1	Straw Model System Design
Group 2	Straw Model System Design
Group 3	Straw Model System Design
Group 4	Straw Model System Design
Workshop Concludes	

Group Introductions by Table

Please stand and share your:

– Name
– Organization
– Technology Interests